The Offshore Floating Type Wave Power Device "Mighty Whale" Open Sea Tests

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1. Introduction

JAMSTEC has been engaged in development of ocean-wave energy extraction technology for many years now. In particular, work began in 1987 on "Mighty Whale", which is a floating wave energy device based on the oscillating water column (OWC) principle. It converts wave energy into electric energy, and produces a relatively calm sea behind. This calm area can be utilized for varied applications such as fish farming. Theoretical investigations and model tests in 2 and 3 dimensional wave tanks led to an understanding of the hydrodynamic behavior of the device, and provided information that allowed safe and economical design of the prototype for open sea tests (Length 50 m, Breadth 30 m, Depth 12 m). Detailed design was completed in 1996. Construction began in January 1997 at the Ishikawajima Harima Heavy Industries Co., Ltd. (IHI) shipyard in Aioi City, Hyogo Prefecture.

Prototype construction was completed by May 1998. Following construction, the prototype was towed to the test location near the mouth of Gokasho Bay in Mie Prefecture. Tests were begun in September 1998, after final positioning and mooring operations was completed. The experiments are expected to continue for approximately 2 years. Results are expected to provide a realistic understanding of the performance, safety, and economic features of the device.

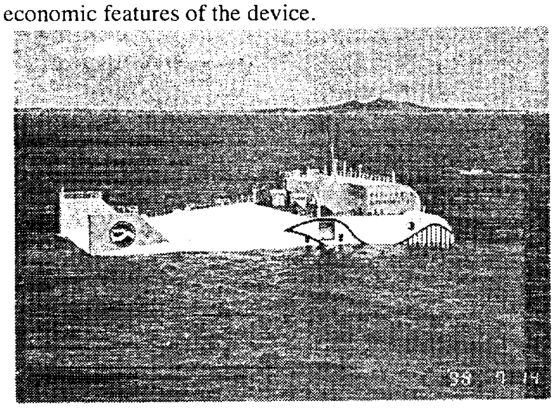

Figure 1 The Prototype

2. Outline of "Mighty Whale"

2.1 System Outline

The "Mighty Whale" is a steel floating structure with the appearance of a whale as shown on Figure 1 which has an air chamber section for absorbing the wave energy at the front (windward), buoyancy tanks and a stabilizer sloped for reducing pitching motion in the waves. Each air chamber has an opening at the top where an air turbine power generator is installed. The under water front wall of each air chamber is open to allow entry of the wave. When a wave enters the air chamber, the water surface inside it moves up and down, producing an oscillating airflow which passes through the opening at the top of the air chamber. This airflow is used to drive the air turbine and generator. This is a wave power energy converter of oscillating water column type.

The air turbines mounted on the "Mighty Whale" are Wells turbines featuring stable rotation of the same direction in an oscillating airflow.

2.2 Functions[1)]

The functions of "Mighty Whale" are wave energy absorption and wave height dissipation. Figures 2 and 3 show the effectiveness of "Mighty Whale" at these functions, as obtained through tank experiments using scale models. Figure 2 shows the wave energy absorption characteristics with respect to the wavelength of incident waves and demonstrates that the maximum efficiency is around 50%. Figure 3 shows the wave height dissipation characteristics (transmitted wave height / incident wave height) and suggests that the device can reduce the heights of waves with length up to twice the device length to below half their original height.

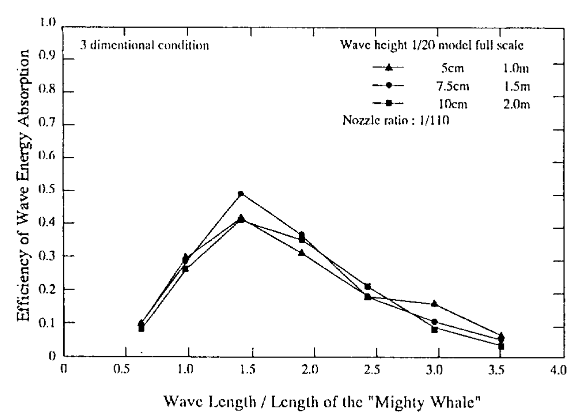

Figure 2 Performance of the Wave Energy Absorption

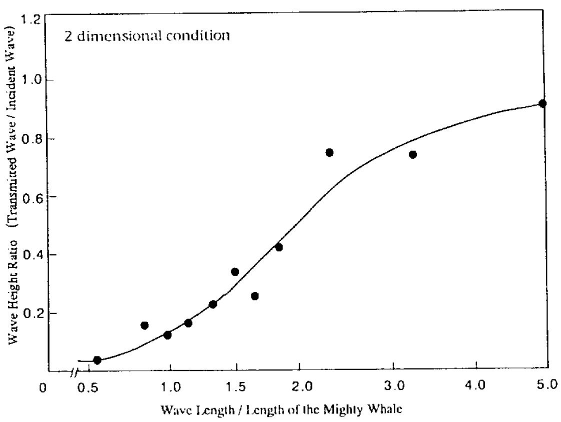

Figure 3 Performance of the Wave Height Dissipation

3. Overview of Prototype

3.1 Design Parameters and Method[2)]

The design parameters associated with environmental loading depend on the assumed return period for the device. The assumed return period determines the severity of the wind/wave conditions (caused for instance by an extreme typhoon) to which the structure may be subjected at least once. The return period to be assumed in a given case depends on the importance of the structure's mission, available fabrication technology, maintenance schedule, and social impact of the structure. In the present case, these considerations made it necessary to assume a return period of 50 years. The environmental loads were then computed using the conditions associated with a 50-year design period. These conditions are shown in Table 1.

Table 1 Environmental Parameters

Steady wind speed	
(10-minute average)	36.4 m/s
(1-minute average)	42.2 m/s
(1-hour average)	34.2 m/s
Current speed	1.2 m/s
Wave height and period	
1/3 significant wave height (max)	8.0 m
1/3 significant wave period (max)	10-15 s
Water depth at test location	40.0 m
Tidal range	
H.W.L.	1.859 m
L.W.L.	0.029 m

3.2 Overview[3)]

The prototype contains three air chambers that convert wave energy into pneumatic energy using the oscillating water column principle. Three buoyancy chambers are provided directly behind the air chambers, two each along the device sides, and three in the aft region. Two vertical fins near the two aft corners and the structural components holding all of the above together comprise the prototype. Above the three air chambers, there is a machine room housing air turbines power generators. A generator is connected to the turbine shaft, through a torque meter. A 50kW generator is connected directly with No.1 turbine (the port air chamber). In addition, this turbine supports a parallel belt-driven 10kW generator. Selection of the generator on the No.1 chamber is made electrically, depending on wave conditions. No.2 (the center air chamber) and No.3 (the starboard air chamber) turbines are each provided with a 30kW generator.

An opening 2.4 m^2 in area is provided on each air chamber. A duct directs airflow from each opening to the respective tandem-type air turbine. Turbine rotational energy is converted into electrical energy by the generators. One section of the machine room is partitioned off from the rest, and contains a compressor driven by a part of the electricity generated as described above. In addition, the partitioned region also contains an auxiliary diesel generator and a battery pack. In the forward section central buoyancy chamber is housed a Control Cabin which serves as an onboard Measurement and Monitoring Station. This space also contains the control system for the air turbines and generators. Details corresponding to the above are shown in the General Arrangement drawing below Figure 4.

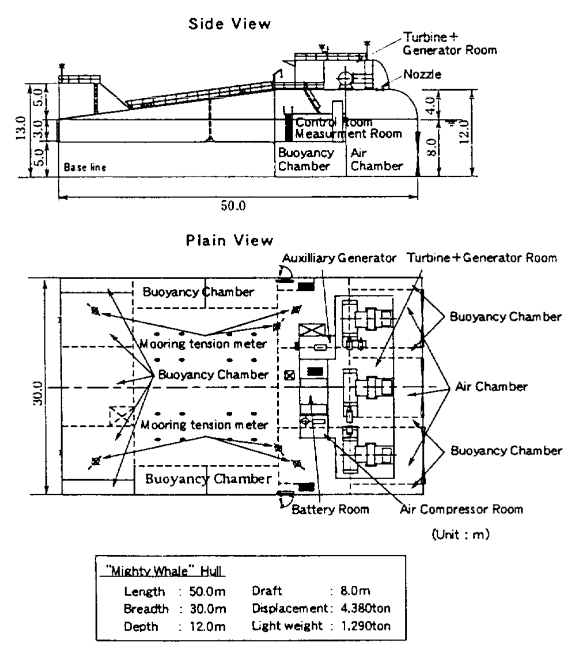

Figure 4 General Arrangement of the Prototype

3.3 Mooring system[4)]

A reliable mooring system is crucial for safe open-sea tests in rough weather. A 6-point mooring system was designed for this project. Chains serving as mooring lines were designed to conform with NK Steel Ships Part P regulations and numerical simulation. The safety factor for the chains was chosen to be 2.0. The anchor design was in accordance with the codes applicable to floating breakwaters (safety factor 1.2). Due consideration was given to the effects of long-period surge motion and heave oscillations, and the resultant variations in the mooring-line loads was minimized. To achieve this, the arrangement shown in Figure 5 was chosen. Four lines in the windward direction and two lines in the leeward direction were arranged and sized as shown in Figure 5. The hull displacement due to steady forces (caused by wind, current, wave-induced drift forces) was minimized by attaching 2 intermediate weights on each line.

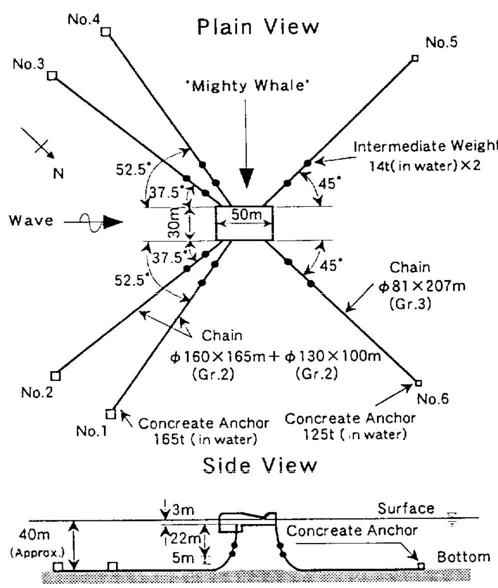

Figure 5 Schematic of the Mooring System

3.4 Measurement and Control System

The prototype is an unmanned floating platform, and is set up to operate automatically. The shore-based measurement and control station is linked to device by a telemetry system. Measurements of device performance, and parameters monitoring on-board equipment and the device as a whole are all transmitted to shore. Figure 6 shows schematic of the measurement and control system. The measurement and control system on board the prototype records atmospheric and oceanic parameters, hull oscillations, mooring forces, water displacements in and out of the air chambers, turbine/generator, rpm, torque, etc. Almost all of the measured data can be analyzed on board. Parameters corresponding to device safety and overall equipment operation are monitored from the shore-based measurement and control station. Monitoring, control, and intervention from the shore are made possible by the telemetry system.

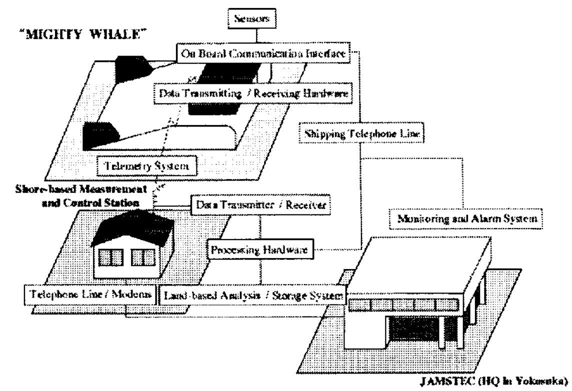

Figure 6 Schematic of the Measurement and Control System

4. Test Site

A map of the test site (Gokasho Bay Nansei Town Watarai District, Mie Prefecture) is shown in Figure 7. The prototype is to be stationed about 1.5km from the bay entrance, at a depth of about 40m. In August 1996 JAMSTEC carried out a survey over a $1km^2$ around the planned test point. The survey indicated a North-South bottom gradient of 1:100, and a depth range of 34-44m. Further, it was also found that except for a small region, the sea-bottom in this area is 94% sandy particulate in composition. The observed wave directions are SE-SSW (summer season : SE-S over 90% of the time, winter season : S-SW over 85% of the time). The 1/3 significant wave height is below 1.0m, and the 1/3 significant period is between 5.0-8.0sec. The annual average wave power density at the site is about 4 kW/m.

The mooring work for the prototype was finished on 13 July 1998.

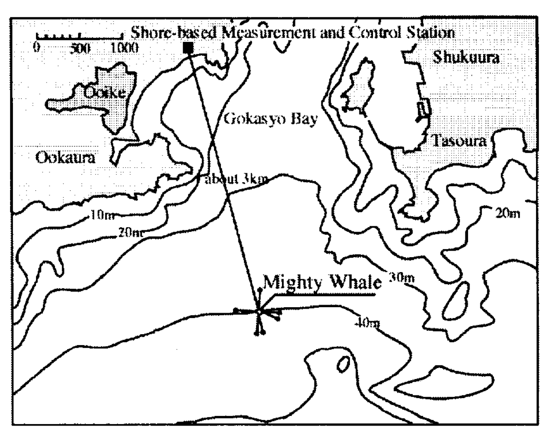

Figure 7 Test Site of the "Mighty Whale"

5. Features of ocean wave condition and response

5.1 Ocean wave condition

Figure 8 shows an example of a time series showing the 1/3 significant wave height and the largest wave height at the test site (Gokasho Bay) from July 1998 to July 1999.

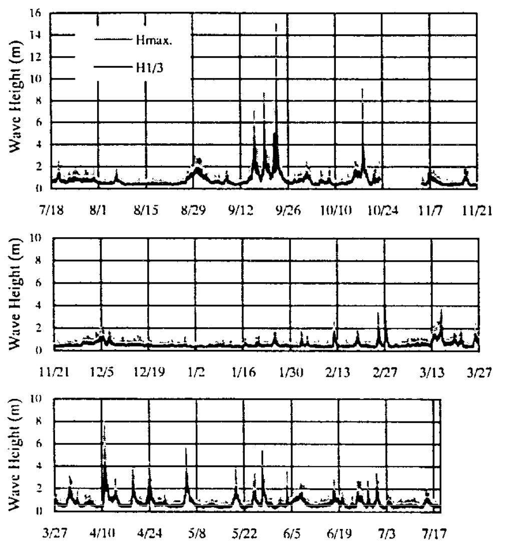

Figure 8 Variation of significant and maximum wave height

Table 2 shows the frequency distribution of the significant wave. The data are measured by pressure-type wave gages on the sea bed 50m ahead of "Mighty Whale". The pressure record is next converted into the surface wave record. From the frequency distribution table of Table 2, it is seen that significant wave height 0.5m and significant wave period 6 sec are the most predominant conditions at the test site. The test site is relatively calm in general, but it was confirmed that the wave height rose greatly in severe weather. Because of this, the design conditions for structural strength and mooring system are severe.

The mooring system requires a large diameter chain for the same reason. In September 1998, after the start of the open sea tests, many large typhoons approached the device, and a 15m high wave (equal to the design condition) was observed. However, the corresponding motion response and mooring tension could not be measured because of trouble with the resistive load. With subsequent diver investigations, it was confirmed that there was no movement of anchors and no breakage of the chains. The safety of the mooring system was confirmed by this investigation.

5.2 Floating body motion and mooring tension

Figure 9 show an example of "Mighty Whale" position in severe weather (significant wave height: 3.36m, significant wave period: 8.8 sec., average wind velocity: 13.6m/s, current velocity: 0.13m/s) of April 10th, 1999 (18:50~19:10) measured by DGPS. The steady displacement of "Mighty Whale" is about 15 m, and it is seen to move greatly in the NW direction. However, this motion is seen to take place about the installation point as the origin. The direction of action wave and current forces was from Starboard side (the W direction). The wind was from the port side (the E direction). It can be seen that the body experiences steady drift force in addition to the steady wind force. In addition, Figure 10, 11 show the time series of incident wave height, wind velocity, floating body motion, mooring tension and corresponding spectra. The time

Table 2 Frequency distribution of significant wave

		Significant Wave Height (m)												
		·0.5	0.5·1.0	1.0·1.5	1.5·2.0	2.0·2.5	2.5·3.0	3.0·3.5	3.5·4.0	4.0·4.5	4.5·5.0	5.0·5.5	5.5·	Total
Significant Wave Period (sec)	·3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3·4	2.43	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.24
	4·5	16.30	2.65	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.96
	5·6	15.37	6.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.53
	6·7	4.38	15.38	0.43	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.27
	7·8	0.24	13.51	2.58	0.30	0.14	0.00	0.02	0.01	0.00	0.00	0.00	0.00	16.81
	8·9	0.00	4.83	3.78	0.92	0.18	0.08	0.08	0.05	0.01	0.00	0.00	0.01	9.95
	9·10	0.00	1.21	2.02	1.12	0.56	0.12	0.05	0.03	0.04	0.00	0.01	0.00	5.17
	10·11	0.00	0.21	1.05	0.56	0.37	0.16	0.16	0.02	0.01	0.02	0.01	0.01	2.58
	11·12	0.00	0.01	0.33	0.18	0.19	0.19	0.13	0.03	0.02	0.00	0.00	0.02	1.09
	12·13	0.00	0.00	0.00	0.09	0.03	0.03	0.02	0.04	0.02	0.01	0.01	0.01	0.25
	13·14	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.00	0.00	0.01	0.00	0.01	0.08
	14·	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.06
	Total	38.72	44.78	10.22	3.26	1.52	0.61	0.49	0.18	0.09	0.06	0.03	0.06	100.00

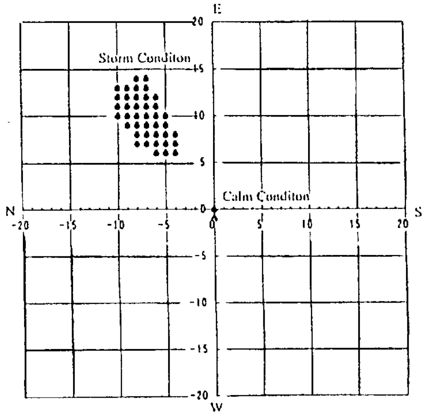

Figure 9 Position of M.W. under storm and calm condition

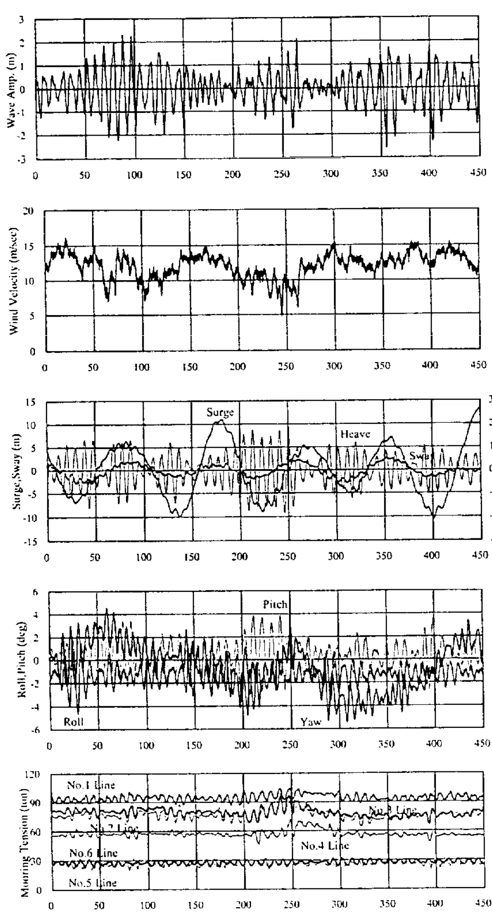

Figure 10 Time series of wave height, wind speed, motions and mooring tensions under storm condition (10 April, 1999)

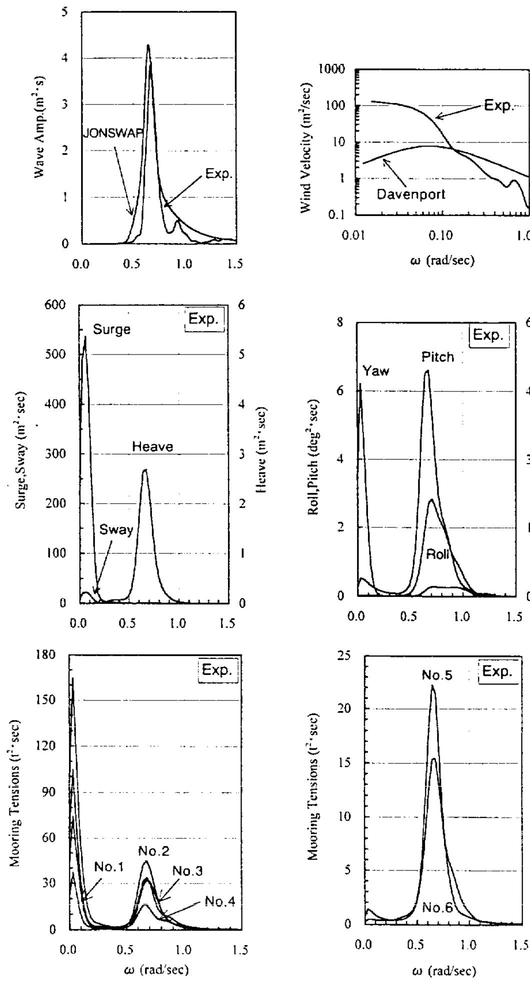

Figure 11 Spectra of wave height, wind speed, motions and mooring tensions under storm condition (10 April 1999)

series records shown are for 10 min, while the spectra are based on 20-min records. It is seen that the slow drift oscillation is significant in surge, sway, and yaw.

The largest surge and yaw are respectively about 15m and about 4m, and about 20 degrees(amplitude). The effect of this slow drift oscillation is also seen in the time series of the mooring tension. Especially, the effect of yaw is strongly felt, and the mooring tension also increases, when yaw is large. Based on wave tank experiments on 1/40-scale models at the design stage, the surge and sway periods are about 100 sec, and the yaw period is about 90sec. The values for surge and sway agree with the period of slow drift oscillation seen in Figure 11. The slow drift oscillation period for yaw is longer than expected from the model tests. The reason for this is being examined currently, and the effect of long-period waves and current are included in this study.

6. Conclusion

In this paper, open sea results for "Mighty Whale" motion and mooring tension time series and spectra were presented.

It was confirmed that the slow drift oscillation of the floating body, which becomes an important factor in the mooring system design for "Mighty Whale" is significant even in the open-sea tests. In this case, the effect of slow drift in yaw on mooring tension is also considerable. This confirmed that slow drift oscillation effects must be considered in mooring system design. It is necessary to consider further the effect of long-period waves and current on slow-drift oscillation.

In the future, a more detailed analysis of wind, wave, current, motion response, and mooring tension will be carried out. The results will be compared with numerical simulations.

References

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